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Strong adherence to dietary and lifestyle recommendations is associated with decreased type 2 diabetes risk in the AusDiab cohort study

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ABSTRACT

We aimed to determine whether adherence to the Australian dietary guidelines and an index of healthy behavior was associated with a lower risk of type 2 diabetes (T2D) and to provide estimates of the proportion of preventable cases. Participants of the AusDiab cohort study were followed for 12 years (n = 6242), starting from May 1999, during which T2D cases were identified. The associations between T2D risk and a score of adherence to the dietary guidelines, its components, and a score of adherence to an index of healthy behaviors, (which included smoking, recreational physical activity, waist circumference and adherence to the dietary guidelines), were estimated using Cox proportional hazards ratios (HR) and 95% confidence intervals. The proportion of preventable cases was estimated using the population attributable fraction (PAF). Strong adherence to the dietary guidelines was not associated with T2D risk (HR = 0.64 [95% CI 0.39–1.06]), unless moderate alcohol consumption was considered as beneficial instead of no alcohol consumption (HR = 0.59 [0.36–0.96]). However, strong adherence to the guidelines regarding fruit and dairy intake were both associated with decreased risk of T2D (HR = 0.68 [0.51–0.91]; 0.56 [0.38–0.84], respectively) and could have prevented 23–37% of cases (PAF = 23.3% [7.3–38.2]; 37.1% [14.6–56.0], respectively). Strong adherence to the index of healthy behaviors was associated with decreased risk of T2D (HR = 0.30 [0.17–0.51]) and estimated to prevent almost 60% of T2D (PAF = 59.4% [34.3–76.6]). More than half of T2D cases could be preventable in Australia through modifying health behavior. These results could serve as a basis for prevention programs based on lifestyle modification.

1. Introduction

The prevalence of diagnosed diabetes in Australia was estimated at 5.1% in 2014–2015, with an additional 3.1% of the population having impaired fasting glucose (Australian Bureau of Statistics, 2015). With the prevalence continually increasing, and diabetic complications following, it is important to prevent at the population level (Baker IDI Heart and Diabetes Institute, 2012).

Diet is an important aspect in the etiology of type 2 diabetes (T2D), yet adherence to the Australian dietary recommendations and its impact on the development of T2D has not been evaluated sufficiently. Only one study has examined this relationship, and used two dietary indices (the Australian Recommended Food Score (ARFS) and the Dietary Guideline Index (DGI)) based on former recommendations (Alhazmi et al., 2014). The DGI was associated with a decreased risk of T2D and the AFRS was not associated. As the current literature appears unclear about the effect of adherence to the Australian dietary guidelines on the development of T2D, exploring this relationship is important to determine the efficacy of the dietary recommendations in T2D prevention.

T2D is a condition with modifiable risk factors besides the diet, such as overweight or obesity, physical inactivity, and smoking. Management of these factors could prevent between 78 and 91% of cases, but the preventable proportion has not yet been estimated in an

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Australian population (Hu et al., 2001; Steinbrecher et al., 2011; Lv et al., 2017; Mozaffarian et al., 2009; Laaksonen et al., 2010). The population attributable fraction (PAF) can be used to estimate the preventable proportion of a disease in a population, taking into account both the prevalence of the risk factor in the population and the magnitude of its association. Estimating the impact of modifiable behaviors on T2D could provide invaluable information to public health decision makers.

Therefore, our objective was to quantify the relationship between the adherence to an index of healthy behaviors, to each characteristic of the index, and to each component of the Australian Dietary Guidelines with the risk of T2D in a large, population-based study. In addition, we estimated the PAF of adherence to the index of healthy behaviors, each characteristic of the index, and each component of the dietary guidelines to determine the percentage of preventable cases of T2D in the Australian population.

2. Methods

2.1. Study cohort

The Australian Diabetes, Obesity and Lifestyle Study (AusDiab) is a longitudinal, population-based national survey of adults (Dunstan et al., 2002). Briefly, the baseline survey was conducted between May 1999 and December 2000 throughout Australia. The study was approved by the Baker Heart and Diabetes Institute Ethics Committee and written informed consent was obtained from all participants. Eligible participants were ≥ 25 years of age and residing at their address for ≥6 months. The baseline survey consisted of an initial household interview and was followed by biomedical exams. Of 20,347 eligible participants, the participation rate in the household and biomedical exams was 55%, resulting in a baseline study population of 11,247.

Two rounds of follow-up occurred, in 2004–2005 and 2011–2012, in which participants completed biomedical examinations. Participants excluded from these analyses were those with prevalent diabetes status at baseline (n = 1112), who did not participate in either follow-up (n = 3757), who did not complete the dietary questionnaire (n = 86), and those with extreme values for the ratio between energy intake and required energy (i.e. the 1st and 99th percentiles of the distribution in the population) (n = 50), leaving 6242 participants in the analyses.

2.2. Assessment of risk factors and T2D

At baseline and follow-ups, anthropometric measures and fasting blood samples were collected and participants completed interviewer-administered questionnaires on health and social factors (Dunstan et al., 2002; Magliano et al., 2008). Participants underwent a standard 75 g oral glucose tolerance test and T2D was classified as fasting plasma glucose ≥7.0 mmol/L, 2 h plasma glucose ≥ 11.0 mmol/L or current treatment with insulin or oral hypoglycemic agents (World Health Organization, 2006).

2.3. Assessment of dietary intake

Dietary intake was assessed at baseline using a self-administered, validated, food frequency questionnaire (FFQ) developed by the Cancer Council of Victoria (Ireland et al., 1994). This semi-quantitative FFQ included 80 items over the previous 12 months. A total of 10 frequency categories were included in the FFQ, ranging from "never" to "three or more times per day". The average daily intake of each item, in grams, was then computed.

2.4. Constructing the index of adherence to dietary guidelines

An index of adherence to the Australian Dietary Guidelines was created based on the 2013 recommendations, which specifies the recommended number of servings per day, by sex and age, for each of the five food groups: (Australian Bureau of Statistics, 2015) Fruit; 2) Vegetables: vegetables and legumes/beans; 3) Grains: grain (cereal) foods; 4) Dairy: milk, yogurt, cheese and/or alternatives; 5) Proteins: lean meats and poultry, fish, eggs, tofu, nuts/seeds, and legumes/beans) (National Health and Medical Research Council, 2013), as well as "no more than two standard drinks of alcoholic beverages on any day" (1 standard drink = 10 g of ethanol) (Supplemental Table 1) (Australian Government Department of Health, 2013). The dietary index was therefore determined by adherence to recommendations of six components: Fruit, Vegetables, Grains, Dairy, Proteins and Alcohol. The number of servings was calculated by taking the amount consumed per day reported in the FFQ and dividing it by the quantity outlined as a serving for the particular food item. For example, a serving of cooked lean poultry is 80 g, whereas a serving of cooked lean red meat is 65 g. The number of servings for each food group was then summed to obtain a final quantity for each food group for each individual.

For each age group, (25–50, 51–69, ≥70 years), the level of adherence to the dietary guidelines was determined. We considered those within a half serving range of the recommendations as strong adherers. For example, 6 servings of grains are recommended for men aged 19–70 years. A man consuming 5.5–6.4 servings of grains was considered a strong adherer, a man consuming 2.75–5.4 servings of grains an intermediate adherer, a man consuming < 2.75 a weak adherer and a man consuming ≥6.5 servings of grains was considered as "exceeding the limits". Concerning alcohol, no alcohol intake was considered as "strong adherence", < 1 standard drink was considered as "intermediate adherence", 1–1.9 standard drinks as "weak adherence" and ≥2 standard drinks as "exceeding the limits". The final index for the overall adherence to the dietary guidelines was determined by the total number of components to which the individual was considered to have strong adherence and ranged from 0 to 6.

2.5. Constructing the index of healthy behaviors

An index of healthy behaviors was created based on an index developed by Dartois et al. (Dartois et al., 2014). Four lifestyle behaviors comprised our a priori index: tobacco smoking, level of recreational physical activity, waist circumference, and adherence to the dietary guidelines. Individuals were assigned scores based on their adherence to recommendations set by either the Australian Department of Health or the World Health Organization (Australian Government Department of Health, 2013; World Health Organization, 2017a; World Health Organization, 2017b; World Health Organization, 2017c; Australian Government Department of Health, 2015). A score was assigned for adherence to each individual characteristic of the index, with a score of 1 to those considered to demonstrate strong adherence to the recommendations, 0.5 to those showing intermediate adherence, and 0 to those showing weak adherence. For example, individuals received a score of 1 if they were non-smokers, had sufficient recreational physical activity (≥150 min/week), a low weight-related health risk (waist circumference < 94 cm for men and < 80 cm for women), or strong adherence to the dietary guidelines (strong adherence to the recommendations for ≥3 components). The criteria used to score each individual can be found in Table 1. The final score was obtained by summing the score from each lifestyle behavior to obtain a score that ranged from 0 to 4, with 4 representing strong adherence to all recommendations.

2.6. Statistical analyses

Cox multivariable regression models with age as the timescale were used to estimate hazard ratios (HR) and 95% confidence intervals (CI) of T2D risk for each component of the dietary index, for each characteristic of the index of healthy behaviors, and for the index of healthy behaviors itself. The time at entry was the date of the baseline physical

Table 1
Criteria for creation of the healthy behavior index based on four lifestyle characteristics.

Behavior	Weak adherence (0)	Intermediate adherence (0.5)	Strong adherence (1)
Tobacco smoking	Current smoker	Former smoker	Non-smoker
Recreational physical activity (min/week)	< 75	75–149	≥150
BMI (kg/m^2)[a]	≥30	25–29	< 25
Waist circumference (cm)			
Men	≥102	94–101	< 94
Women	≥88	80–87	< 80
Adherence to Australian dietary guidelines	Index score = 0	Index score 1–2	Index score ≥ 3

[a] BMI was substituted for waist circumference in the sensitivity analyses.

exam and the exit time for those who did not develop T2D was the most recent date they attended a follow-up. For those who developed T2D between the baseline and one of the follow-ups, the exit time taken was a randomly generated date between baseline and the date of follow-up they were diagnosed, using the *runiform* function in Stata. Random point value imputation is believed to produce estimates close to the true incidence rate (Vandormael et al., 2018). Restricted cubic spline regression with 3 knots was also performed to visualize potential non-linear relationships between the number of servings per day of each food group and the risk of T2D.

Confounding factors considered for adjustment in the multivariate models included: sex, high triglycerides (no; yes: ≥2.0 mmol/L), low HDL cholesterol (no; yes: < 1.0 mmol/L), family history of diabetes (no vs. yes), recreational physical activity (sedentary: < 75 min/week; insufficient: 75–149 min/week; sufficient: ≥150 min/week), smoking status (current smoker; ex-smoker; non-smoker), energy intake (kJ/day), hypertension (no vs. yes: ≥140/90 mm Hg) and waist circumference group (low weight-related health risk: < 94 cm for men/ < 80 cm for women; increased weight-related health risk: 94–101 cm for men/80–87 cm for women; high weight-related health risk: ≥102 cm for men/≥88 cm for women), and the level of education (secondary school/trade school/technician's certificate or less vs. Bachelor's degree, post graduate degree, nursing or teaching qualification).

2.7. Estimation of population attributable fractions

The PAFs were computed to determine the proportion of T2D cases that could have been avoided with full adherence to the recommendations, if all other risk factors had remained unchanged. Under the assumption of a causal relationship and no change in participant's characteristics over time, PAFs were calculated for strong adherence to recommendations for each component of the dietary index, each characteristic of the index of healthy behaviors (a score of 1), and the index of healthy behaviors (a score ≥ 3.5). Using methods developed by Dartois et al. and Spiegelman et al., point estimates and 95% CIs were computed with adjustments for potential confounders (Dartois et al., 2014; Spiegelman et al., 2007). All statistical tests were considered significant at $P < 0.05$. All analyses used Stata version 12, except for the PAFs which were estimated using SAS version 9.3.

2.8. Sensitivity analyses

As a moderate consumption of alcohol may be beneficial in preventing T2D (Carlsson et al., 2005), we tested the substitution of moderate alcohol consumption (0.5–0.9 standard drinks per day; standard drink = 10 g ethanol) as beneficial and considered individuals with moderate consumption as strong adherers to the recommendations. We also tested the substitution of waist circumference by category of BMI (normal: < 25 kg/m^2; overweight: 25–29 kg/m^2; obese: ≥30 kg/m^2). Because the prevalence estimates in AusDiab may not be fully representative of the population, we also estimated PAFs using updated prevalence estimates from the 2014–2015 Australian National Health Survey and unadjusted hazard ratios with the formula:

$$\frac{(P(E) \times (RR - 1))}{((P(E) \times (RR - 1)) + 1)}$$

Where P(E) is the proportion of the population exposed to the factor and RR is the relative risk of T2D associated with the factor (Flegal et al., 2015).

Finally, we ran logistic regression models including a factor for diagnosis of T2D before or after the first follow-up to determine whether the estimates were close to those predicted by the random point values imputed in the Cox regression models.

3. Results

3.1. Baseline characteristics

Over 63,086 person years of follow-up, 376 cases of T2D were diagnosed. T2D incidence was 6.0 [5.39–6.59] per 1000 person years. Median follow-up time was 11.7 years, (ranging from 2.0 to 13.1 years). Those most strongly adhering to the index of healthy behaviors were slightly younger, more educated, had no family history of diabetes, were normotensive, had triglycerides < 2 .0mmol/L, an HDL cholesterol level ≥ 1 .0mmol/L and reported significantly higher energy intakes (Table 2).

3.2. Adherence to the dietary guidelines

Strong adherence to fruit and dairy recommendations was significantly associated with a 32% and 44% decreased risk of T2D, respectively, after adjustment for confounders (Table 3). However, exceeding the limits of recommended fruit intake did not appear beneficial for T2D risk (HR = 1.04 [95% CI 0.76–1.43]). Strong adherence to recommendations for vegetables, grains, protein-rich foods, and alcohol (not drinking) were not associated with T2D risk (HR = 0.83 [0.37–1.88], HR = 1.08 [0.72–1.59], HR = 1.10 [0.75–1.61], HR = 0.86 [0.59–1.26], respectively) even after further adjustment for adherence to the guidelines for the remaining dietary components (*results not shown*). But, exceeding the limits for protein-rich foods was associated with a 56% increased risk of T2D (HR = 1.56 [1.01–2.43]).

Cubic spline regression for the dose-response association between the number of servings/day of fruit and T2D risk indicated a curvilinear association, where up to 3.2 servings of fruit per day was associated with a risk reduction ($p = 0.0001$), after adjustment for confounders (Supplemental Fig. 1). Increasing dairy servings was strongly inversely associated with a decreased risk of T2D ($p = 0.003$), whereas increasing servings of protein-rich foods was associated with an increased risk ($p = 0.03$). Finally, the number of standard drinks per day, servings of vegetables and grains were not significantly associated with T2D ($p = 0.09$, $p = 0.09$, $p = 0.43$, respectively).

Table 2
Baseline characteristics of the study population by adherence group to the healthy behavior index; AusDiab cohort study (n = 6242), 1999-2012[b,c].

Variables	Overall population (n = 6242)	Weak adherence (< 2.5) (n = 2938)	Intermediate adherence (2.5–3.4) (n = 2568)	Strong adherence (≥3.5) (n = 736)
Age (years)	50.3 ± 12.5	51.1 ± 12.3	49.9 ± 12.6	48.4 ± 12.9
Sex (n, (%))				
Male	2813 (45.1)	1325 (45.1)	1142 (44.5)	346 (47)
Female	3429 (54.9)	1613 (54.9)	1426 (55.5)	390 (53)
Level of education (n, (%))				
Secondary school, trade, technician's certificate or less	4128 (66.1)	2103 (71.6)	1615 (62.9)	410 (55.7)
Bachelor's degree, post-graduate, nursing or teaching qualification	2114 (33.9)	835 (28.4)	953 (37.1)	326 (44.3)
Smoking status (n, (%))				
Non-smoker	3732 (59.8)	1230 (41.9)	1786 (69.6)	716 (97.3)
Ex-smoker	1791 (28.7)	1082 (36.8)	689 (26.8)	20 (2.7)
Current smoker	719 (11.5)	626 (21.3)	93 (3.6)	0 (0)
Family history of diabetes (n, (%))				
No	5110 (81.9)	2372 (80.7)	2113 (82.3)	625 (84.9)
Yes	1132 (18.1)	566 (19.3)	455 (17.7)	111 (15.1)
Waist circumference (n, (%))				
Low weight-related health risk	2624 (Australian Institute of Health and Welfare, 2012)	555 (18.9)	1370 (53.4)	699 (95)
Increased weight-related health risk	1678 (26.9)	825 (28.1)	816 (31.8)	37 (5)
High weight-related health risk	1940 (31.1)	1558 (53)	382 (14.9)	0 (0)
BMI (kg/m^2) (n, (%))				
Normal (< 25)	2466 (39.5)	698 (23.8)	1234 (48.1)	534 (72.6)
Overweight (Elliott et al., 2002; Sanchez-Lozada et al., 2008; Cooper et al., 2012; Zino et al., 1997; Asgard et al., 2007)	2569 (41.2)	1319 (44.9)	1056 (41.1)	194 (26.4)
Obese (≥30)	1207 (19.3)	921 (31.4)	278 (10.8)	8 (1.1)
Recreational physical activity (n, (%))				
Sedentary (< 75 min)	941 (15.1)	1695 (57.7)	326 (12.7)	0 (0)
Insufficient (75–149 min)	1895 (30.4)	426 (14.5)	377 (14.7)	11 (1.5)
Sufficient (≥150 min)	3406 (54.6)	817 (27.8)	1865 (72.6)	725 (98.5)
Hypertension (n, (%))				
Normal	4545 (72.8)	1999 (68)	1954 (76.1)	592 (80.4)
Hypertensive (≥140/90 mm Hg)	1697 (27.2)	939 (32)	614 (23.9)	144 (19.6)
Triglycerides (n, (%))				
< 2.0 mmol/L	5000 (80.1)	2163 (73.6)	2170 (84.5)	667 (90.6)
≥2.0 mmol/L	1242 (19.9)	775 (26.4)	398 (15.5)	69 (9.4)
HDL cholesterol (n, (%))				
≥1.0 mmol/L	5659 (90.7)	2563 (87.2)	2387 (93)	709 (96.3)
< 1.0 mmol/L	583 (9.3)	375 (12.8)	181 (7.1)	27 (3.7)
Daily energy intake (kJ/day)	8059 ± 2920	7911 ± 2926	8054 ± 2907	8670 ± 2894
Adherence to dietary guidelines (n, (%))				
Fruit				
Weak adherence	1743 (27.9)	1065 (36.3)	569 (22.2)	109 (14.8)
Intermediate adherence	1828 (29.3)	936 (31.9)	750 (29.2)	142 (19.3)
Strong adherence	1714 (27.5)	542 (18.5)	812 (31.6)	360 (48.9)
Exceeding the limits	957 (15.3)	395 (13.4)	437 (17)	125 (17)
Vegetables				
Weak adherence	3744 (60)	1782 (60.7)	1538 (59.9)	424 (57.6)
Intermediate adherence	2337 (37.4)	1090 (37.1)	962 (37.5)	285 (38.7)
Strong adherence	109 (1.8)	40 (1.4)	45 (1.8)	24 (3.3)
Exceeding the limits	52 (0.8)	26 (0.9)	23 (0.9)	3 (0.4)
Grains				
Weak adherence	877 (14.1)	485 (16.5)	330 (12.9)	62 (8.4)
Intermediate adherence	3091 (49.5)	1543 (52.5)	1254 (48.8)	294 (40)
Strong adherence	931 (14.9)	349 (11.9)	388 (15.1)	194 (26.4)
Exceeding the limits	1343 (21.5)	561 (19.1)	596 (23.2)	186 (25.3)
Dairy				
Weak adherence	2050 (32.8)	1078 (36.7)	801 (31.2)	171 (23.2)
Intermediate adherence	2939 (47.1)	1424 (48.5)	1212 (47.2)	303 (41.2)
Strong adherence	960 (15.4)	293 (10)	440 (17.1)	227 (30.8)
Exceeding the limits	293 (4.7)	143 (4.9)	115 (4.5)	35 (4.8)
Protein				
Weak adherence	736 (11.8)	352 (12)	314 (12.2)	70 (9.5)
Intermediate adherence	2424 (38.8)	1189 (40.5)	1002 (Layman et al., 2008)	233 (31.7)
Strong adherence	1813 (29.1)	693 (23.6)	799 (31.1)	321 (43.6)
Exceeding the limits	1269 (20.3)	704 (24)	453 (17.6)	112 (15.2)
Alcohol				
Weak adherence	1056 (16.9)	449 (15.3)	451 (17.6)	156 (21.2)
Intermediate adherence	2757 (44.2)	1370 (46.6)	1091 (42.5)	296 (40.2)
Strong adherence	772 (12.4)	302 (10.3)	344 (13.4)	126 (17.1)
Exceeding the limits	1657 (26.6)	817 (27.8)	682 (26.6)	158 (21.5)
Overall dietary adherence				
Weak (0 points)	2066 (33.1)	1365 (46.5)	701 (27.3)	0 (0)

(continued on next page)

Table 2 (*continued*)

Variables	Overall population (n = 6242)	Weak adherence (< 2.5) (*n* = 2938)	Intermediate adherence (2.5–3.4) (*n* = 2568)	Strong adherence (≥3.5) (*n* = 736)
Intermediate (1–2 points)	3786 (60.7)	1505 (51.2)	1682 (65.5)	599 (81.4)
Strong (≥3 points)	390 (6.3)	68 (2.3)	185 (7.2)	137 (18.6)

[b] Values are means ± SDs or n (% of category).
[c] Refer to Supplementary Table 1 for definitions of the dietary food group adherences.

3.3. Adherence to the index of healthy behaviors

Strong adherence to the Australian dietary guidelines was not associated with T2D risk (HR = 0.64 [0.39–1.06]), though an inverse relationship was suggested (Table 4). Not smoking, performing sufficient physical activity, and a waist circumference with low health-related risk all demonstrated strong inverse associations with T2D risk. Strong adherence to the index of healthy behaviors was associated with a 70% decreased risk of T2D after adjustments (HR = 0.30 [0.17–0.51]) and cubic spline regression suggested a significant, linear, inverse relationship ($p < 0.0001$) (Fig. 1).

3.4. Population attributable fractions

The population attributable fraction was strongest for waist circumference, even after adjustment for confounders, suggesting that > 40% of cases of T2D could be prevented if everyone had had waist circumferences < 94 cm (men) or < 80 cm (women) (PAF = 42.6% [27.5%–55.7%]) (Fig. 2) and almost 20% of new onset T2D could have been prevented with sufficient exercise (PAF = 17.3 [7.5–26.8]). The PAF for smoking was not statistically significant (PAF = 7.7 [−1.5–16.8]). Strong adherence to the dietary guidelines for fruit consumption suggested > 20% of T2D could have been prevented (PAF = 23.3 [7.3–38.2]), and those for dairy may have prevented 37% of cases (PAF = 37.1 [14.6–56.0]). Strong adherence to the dietary recommendations (index score ≥ 3) was not statistically significant (PAF = 30.8 [−3.0–58.1]). Overall, strong adherence to the index of healthy behaviors indicated that almost 60% of T2D cases could have been prevented (PAF = 59.4 [36.2–76.6]).

3.5. Sensitivity analyses

Moderate alcohol consumption was not associated with T2D risk (HR = 0.89 [0.65–1.22]). However, both an intermediate and a strong overall adherence to dietary guidelines revealed an inverse association with T2D risk after adjustment for confounders (HR = 0.80 [0.65–0.99], HR = 0.59 [0.36–0.96], respectively). But, the association between the index of healthy behaviors and T2D did not significantly change (HR = 0.32 [0.19–0.53]). The PAF for moderate alcohol consumption was not statistically significant (PAF = 18.6 [−7.2–42.3]),

Table 3
Cox proportional hazards ratios [95% CI] for risk of incident type 2 diabetes by adherence to the Australian dietary recommendations in the AusDiab cohort study (*n* = 6242), 1999–2012[d].

	Cases/non-cases	Model 1	Model 2	Model 3
Fruit				
Weak adherence	128/1615	REF	REF	REF
Intermediate adherence	103/1725	0.72 [0.55–0.93]	0.79 [0.61–1.03]	0.81 [0.62–1.05]
Strong adherence	80/1634	0.56 [0.42–0.74]	0.65 [0.49–0.88]	0.68 [0.51–0.91]
Exceeding the limits	65/892	0.81 [0.60–1.10]	1.02 [0.74–1.41]	1.04 [0.76–1.43]
Vegetables				
Weak adherence	229/3515	REF	REF	REF
Intermediate adherence	140/2197	0.92 [0.75–1.14]	0.92 [0.74–1.15]	0.89 [0.72–1.11]
Strong adherence	6/103	0.83 [0.37–1.87]	0.77 [0.34–1.75]	0.83 [0.37–1.88]
Exceeding the limits	1/51	0.29 [0.05–2.07]	0.34 [0.05–2.44]	0.29 [0.04–2.10]
Grains				
Weak adherence	53/854	REF	REF	REF
Intermediate adherence	180/2911	0.87 [0.64–1.18]	0.92 [0.67–1.27]	0.96 [0.70–1.31]
Strong adherence	64/867	0.93 [0.64–1.34]	1.03 [0.69–1.52]	1.08 [0.72–1.59]
Exceeding the limits	79/1264	0.76 [0.53–1.08]	0.88 [0.58–1.32]	0.95 [0.63–1.42]
Dairy				
Weak adherence	150/1900	REF	REF	REF
Intermediate adherence	179/2760	0.85 [0.68–1.07]	0.90 [0.71–1.12]	0.93 [0.74–1.17]
Strong adherence	33/927	0.51 [0.34–0.74]	0.55 [0.37–0.82]	0.56 [0.38–0.84]
Exceeding the limits	14/279	0.73 [0.42–1.28]	0.81 [0.46–1.44]	0.84 [0.47–1.50]
Protein				
Weak adherence	40/696	REF	REF	REF
Intermediate adherence	120/2304	0.88 [0.61–1.26]	0.98 [0.68–1.41]	0.94 [0.65–1.35]
Strong adherence	112/1701	1.03 [0.72–1.48]	1.21 [0.82–1.78]	1.10 [0.75–1.61]
Exceeding the limits	104/1165	1.36 [0.94–1.97]	1.85 [1.19–2.87]	1.56 [1.01–2.43]
Alcohol				
Weak adherence	53/1003	REF	REF	REF
Intermediate adherence	164/2593	0.81 [0.60–1.10]	0.86 [0.64–1.17]	0.87 [0.65–1.18]
Strong adherence	59/713	0.63 [0.43–0.92]	0.81 [0.56–1.19]	0.86 [0.59–1.26]
Exceeding the limits	100/1557	0.72 [0.52–1.01]	0.81 [0.58–1.14]	0.84 [0.60–1.18]

*Model 1: sex adjusted model
*Model 2: additionally adjusted for education, smoking status, recreational physical activity, high triglycerides, low HDL cholesterol, family history of diabetes, energy intake,hypertension
*Model 3: additionally adjusted for waist circumference.
[d] Please refer to Supplementary Table 1 for definitions of the adherence categories.

Table 4
Cox proportional hazards ratios [95% CI] for risk of type 2 diabetes by adherence to recommendations for healthy behaviors and by adherence to the healthy behavior index in the AusDiab cohort study (n = 6242), 1999–2012[e].

	Cases/non-cases	Model 1	Model 2
Individual characteristics			
Smoking			
Weak adherence	59/660	REF	REF
Intermediate adherence	115/1676	0.62 [0.45–0.86]	0.70 [0.51–0.97]
Strong adherence	202/3530	0.57 [0.42–0.76]	0.65 [0.48–0.88]
Recreational physical activity			
Weak adherence	160/1861	REF	REF
Intermediate adherence	49/765	0.74 [0.54–1.02]	0.82 [0.59–1.13]
Strong adherence	167/3240	0.59 [0.47–0.73]	0.65 [0.52–0.80]
Waist circumference			
Weak adherence	229/1711	REF	REF
Intermediate adherence	78/1600	0.37 [0.29–0.48]	0.44 [0.34–0.57]
Strong adherence	69/2555	0.23 [0.17–0.30]	0.33 [0.24–0.43]
Dietary adherence			
Weak adherence	130/1936	REF	REF
Intermediate adherence	228/3558	0.91 [0.73–1.13]	0.93 [0.75–1.16]
Strong adherence	18/372	0.68 [0.41–1.11]	0.64 [0.39–1.06]
Behavioral index			
Tertile 1 (< 2.5)	258/2680	REF	REF
Tertile 2 (2.5–3.4)	104/2464	0.45 [0.36–0.57]	0.54 [0.43–0.68]
Tertile 3 (≥3.5)	14/722	0.22 [0.13–0.37]	0.30 [0.17–0.51]
Continuous		0.51 [0.45–0.58]	0.60 [0.52–0.67]

*Model 1: sex adjusted model
*Model 2: additionally adjusted for education, high triglycerides, low HDL cholesterol, family history of diabetes, energy intake, hypertension.
[e] Refer to Table 1 for definitions of the adherence categories.

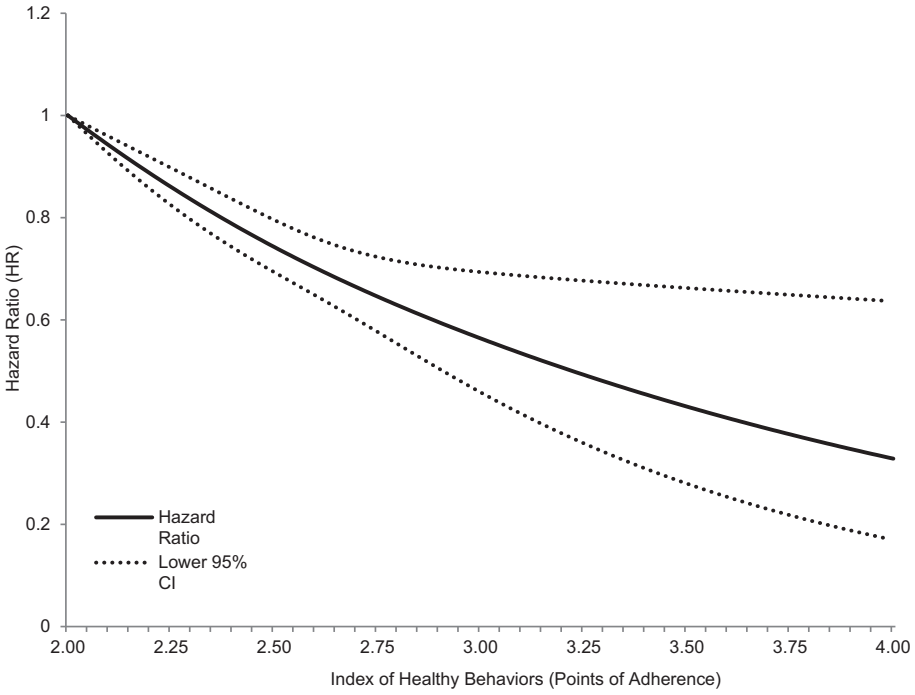

Fig. 1. Cubic spline regression with 3 knots for adherence to the index of healthy behavior and the risk of type 2 diabetes for AusDiab study participants (n = 6242), 1999–2012. Continuous line: hazard ratio, dashed lines: 95% confidence intervals. Model was adjusted for sex, high triglycerides, hypertension, low HDL cholesterol, family history of diabetes, and level of education.

and neither the PAF for adherence to dietary guidelines nor for the index of healthy behaviors significantly changed when moderate alcohol consumption was considered best.

The substitution of BMI for waist circumference did not materially change the associations observed (*results not shown*).

The PAFs estimated using the prevalence values from the 2014–2015 National Health Survey were similar to those estimated from the cohort. They were as follows: 4.3%, 51.1%, 19.1%, −21.6%, 21.1% and 12.8%, for smoking, overweight/obesity, insufficient recreational physical activity, alcohol consumption, and insufficient fruit and vegetable consumption, respectively.

Finally, the point estimates did not significantly change when estimated with logistic regression models including a factor for T2D diagnosis before or after the first follow-up (Supplemental Table 2).

4. Discussion

Strong adherence to the recommendations for fruit and dairy consumption was inversely associated with T2D risk and may have prevented 23–37% of T2D cases, while exceeding the limits of recommended protein-rich food intake was positively associated with T2D risk. Strong adherence to the dietary guidelines was not associated

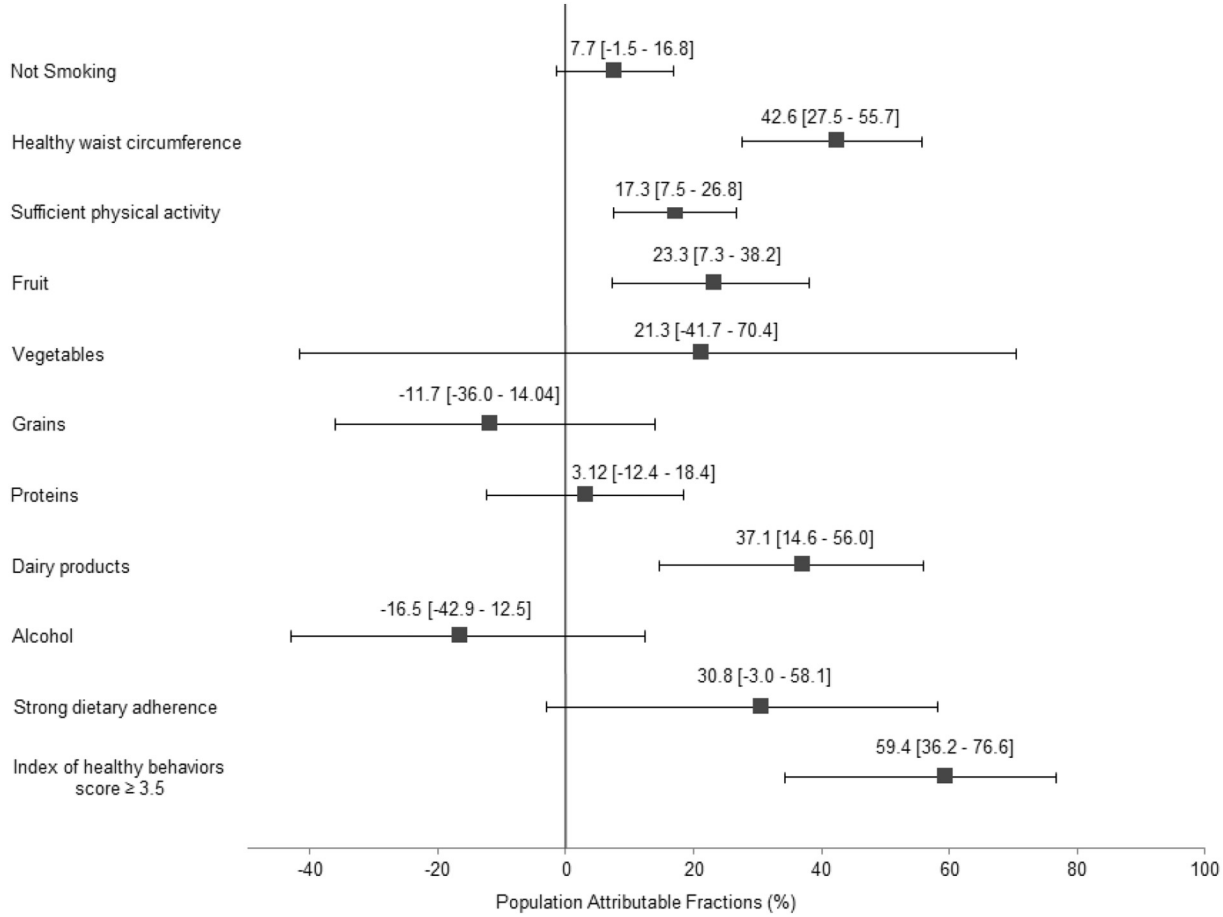

Fig. 2. Population attributable fractions (%) and 95% CI of type 2 diabetes cases that may have been prevented with strong adherence to the recommendations of the dietary guidelines and the index of healthy behaviors in the AusDiab cohort study (n = 6242), 1999–2012.

with T2D risk except when moderate alcohol consumption was considered as beneficial. Strong adherence to the index of healthy behaviors indicated a 70% decreased risk of T2D and that almost 60% of T2D cases could have been prevented in this population.

4.1. Adherence to dietary guidelines for food groups

Meta-analyses have also observed a curvilinear association with restricted cubic spline regression between fruit intake and T2D (Li et al., 2014). It is possible that the true association is curvilinear, as large intakes of fructose may be detrimental (Elliott et al., 2002; Sanchez-Lozada et al., 2008). Total vegetable intake has not been associated with T2D in meta-analyses (Li et al., 2014; Cooper et al., 2012), but vegetable intake has been negatively correlated with markers of DNA oxidation, lipid peroxidation and inflammation (Zino et al., 1997; Asgard et al., 2007; Harding et al., 2008; Dauchet et al., 2008). We hypothesize that the low vegetable consumption, in addition to the lack of variation, (60% of the population had weak adherence), could have driven our estimates towards the null. Strong adherence to grain intake was not associated with T2D risk, likely because risk differs by the type of grain consumed (Schwingshackl et al., 2017; Aune et al., 2013). Future studies should determine the effect of grains, and in particular, whole grains in the Australian population. Inverse relations between dairy intake and T2D have been inconsistently reported in meta-analyses (Gijsbers et al., 2016; Gao et al., 2013; Chen et al., 2014). Grantham et al. have previously analyzed dairy intake in this cohort, and found only an inverse association in men (Grantham et al., 2013). However, our results suggest that more than a third of the cases in this population could have been prevented with the recommended dairy intake. We observed a positive dose-response relationship between protein-rich foods and T2D risk, though studies do not suggest negative effects of high-protein diets (Liu et al., 2015; Layman et al., 2008). However, meta-analyses suggest high intakes of red meat increase T2D risk (Schwingshackl et al., 2017). In this cohort, red meat intake contributed more than half (53%) of the intake of protein-rich foods. Decreasing red meat intake could be beneficial in terms of T2D risk.

4.2. Overall dietary adherence

Alhazmi et al. have previously examined adherence to former versions of the Australian dietary recommendations and T2D using two dietary indices (Alhazmi et al., 2014). The first was the ARFS, and included 9 components, dichotomized based on meeting recommendations or not. The second score was the DGI, which included 13 components and assigned 0–10 points, with 10 indicating optimal intake. The DGI was significantly inversely related with T2D risk (OR = 0.51 [0.35–0.76] Quintile 5 vs 1), but the ARFS was not associated (OR = 0.99 [0.68–1.43]). Although adherence to some of the components was associated with T2D risk in this study, overall adherence to the dietary guidelines was not associated with T2D, except when we considered moderate alcohol consumption as beneficial. If confirmed by others, this could suggest that current guidelines could be updated to maximize effectiveness in T2D prevention.

4.3. Population attributable fractions

Our estimates of the effect of excess weight in the Australian population are between those of other countries, which range from 36 to

77% (China and Finland, respectively) (Steinbrecher et al., 2011; Lv et al., 2017; Laaksonen et al., 2010). We estimated that almost a fifth of incident T2D could have been prevented with sufficient (≥150 min/week) physical activity. Other studies have calculated the effect of eliminating physical inactivity that ranged from 5.2 to 13% (Al et al., 2014). Though the PAF for total adherence to the dietary guidelines was not significant, other studies have estimated an unhealthy diet, (defined by: vegetables, fruit, red meat and wheat), to contribute to the development of 26.5% [15.3–36.9] of incident T2D (Lv et al., 2017). The combination of modifiable health-related behaviors suggests that almost 60% of T2D could have been avoided in this population, which appears more moderate than in previous studies, where ideal health-related behaviors could have prevented approximately 80% of cases (Steinbrecher et al., 2011; Lv et al., 2017; Laaksonen et al., 2010) and in two studies in the US, (the Nurses' Health Study (which had a higher threshold for physical activity), and the Cardiovascular Health Study, (a study including adults > 65 years old)), approximately 90% of cases (Hu et al., 2001; Mozaffarian et al., 2009). The impact of adherence to the dietary guidelines for a single component appears large in this population, however, interventions should not focus on a single target. Studies suggest that people who adopt one healthy behavior are likely to adopt multiple healthy behaviors, and thus multiple behavior interventions may have the potential for a stronger impact (Johnson et al., 2008).

4.4. Strengths and limitations

Potential limitations should be considered. Dietary adherence is based on a single questionnaire at baseline in 1999, thus the data are relatively old and misclassification of exposure is possible. However, the prospective design prevents differential bias in the collection of the dietary data, allowing the study of causation between the diet and T2D. In addition, we estimated PAFs using the most recent prevalence data available in Australia and had similar results. Although we took into account the most important confounding factors, residual confounding cannot be excluded. Finally, selection bias may have occurred despite the fact that we had a large, stratified random sample of the population, as with all volunteer study populations, a “healthy volunteer” selection bias is likely and may have attenuated our associations. There are also several strengths; AusDiab is a large, population-based study and glucose was objectively measured using an OGTT. To our knowledge, this is also the first study to evaluate the association between the main components of the Australian dietary guidelines and the risk of T2D, both by adherence and in a dose-response manner, and to estimate the population-level impact of adherence to these components with other modifiable behaviors. The use of an index to estimate the preventable proportion of T2D is another strength of this study, as most studies estimate PAFs for individual risk factors. But, individual risk factors often co-occur or cluster and may interact with each other, suggesting that an index could provide a more comprehensive estimate (Australian Institute of Health and Welfare, 2012).

5. Conclusion

These results underline the impact that modifiable behavior has on the risk of T2D. Vegetable consumption should be emphasized in the Australian population, but efforts should not be focused on a single component, as the greatest reduction is observed with strong adherence to recommendations for all modifiable behaviors. Interventions should focus on changing these modifiable behaviors in the population.

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Conflict of interest

CD, BB, FB, FM, KR, JS, DJM, GF, none.

Contributions

DJM, GF and CD designed the research; CD analyzed the data and performed the statistical analysis; CD wrote the manuscript; DJM and GF had primary responsibility for the final content; BB, FB, FM, KR, and JS reviewed and commented on the final manuscript. All authors read and approved the final manuscript.

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Appendix A. Supplementary data

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